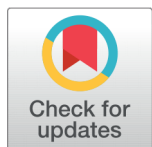


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* **Corresponding author.**

maryamkinsanya@gmail.com

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Geochemistry and mineral chemistry of quartz mica schists within Iseyin-Oyan Schist Belt, Southwestern Nigeria

Maryam Abdus-Salam^{1,2*}, Anthony Bolarinwa³, Akinade Olatunji³, Micheal Fullen⁴, Adegoke Afolabi⁵, Victoria Omotunde¹, Jerry Olajide-Kayode⁶, Olusegun Olisa⁷

¹ Researchers, Department of Geosciences, PAULESI, University of Ibadan Nigeria

² Lecturer, Department of Geology, The Polytechnic Ibadan, Ibadan Nigeria

³ Associate Professors, Department of Geology, University of Ibadan, Nigeria

⁴ Professor, Faculty of Science and Engineering, University of Wolverhampton, WV1 1LY, UK

⁵ Lecturer, Department of Earth Sciences, Ladoke Akintola University of Technology, Ogbomoso Nigeria

⁶ Lecturer, Department of Geology, Osun State University, Osogbo Nigeria

⁷ Lecturer, Department of Geology, Olabisi Onabanjo University, Ago Iwoye, Nigeria

Abstract

Background/Objectives: The Iseyin-Oyan schist belt is made up of metasedimentary rocks, gneisses, granites and pegmatite intrusions. The study was aimed at identifying the schist within this belt and assessing their metamorphism, geochemical characteristics and tectonic origin. **Methods:** Detailed geological field mapping was undertaken where rocks were located, studied in-situ and identified. Samples of the schist were prepared for petrographic studies. Mineralogical contents were determined using X-Ray Diffraction technique. Polished sections were studied for mineral chemistry using Scanning Electron Microscope-Energy Dispersive Spectroscopy. Rock samples were analysed using X-Ray Fluorescence Spectroscopy and Inductively Coupled Plasma Emission Spectrometry. Geochemical data were elucidated using diverse geochemical discrimination diagrams. **Findings:** The schists are quartz mica schists and occur in close association with amphibolites, intrusive granitoids and pegmatites. The Mineral assemblage indicates upper (at the western part) to lower (at the central part) amphibolite facies grade metamorphism in the area. Pyrope-almandine garnets occur in quartz mica schist at the western parts reinforcing higher pressure-temperature metamorphic conditions. The concentration (in %) of SiO₂ ranged from 56.4-71.6; Al₂O₃, 13.7-21.1; Fe₂O₃, 2-8; MgO, 0.7-2.4; and K₂O, 2.1-5.5 supporting the evidence for differential degrees of metamorphism. Large iron lithophile and high field strength elements are similar to the average upper continental crust. Pronounced negative Europium anomaly pointed to the major roles played by feldspars during the geological processes. Plagioclase ranged from albite-oligoclase and oligoclase-andesine. The precursors of the quartz mica schist are possibly arkosic and greywacke sands deposited within the active continental margins. Evidence of uplift and

overturning suggested for the differential metamorphism may be due to these events usually associated with active continental margins. **Applications:** This study has identified the once named undifferentiated schist in the study area to be quartz mica schist with details in their grades of metamorphism elucidated.

Keywords: Quartz mica schist; geochemistry; mineral chemistry; Iseyin-Oyan schist belt; precambrian basement complex

1 Introduction

The Iseyin-Oyan schist belt, within the southwestern part of Nigeria, ([Figure 1](#)) is one of the of Upper Proterozoic supracrustal rocks which have been infolded into the ancient polymetamorphic migmatite–gneiss basement complex rocks.⁽¹⁻³⁾ The syn- to late-tectonic Pan-African intrusive granitoids intrudes the supracrustals and the migmatite gneiss complex.^(2,3)

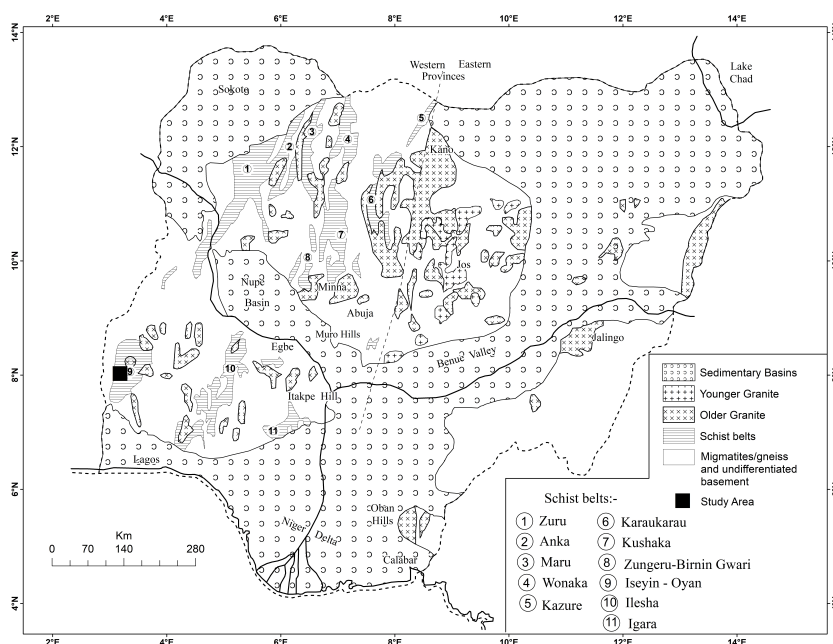


Fig 1. Localization of the study area in the Iseyin- Oyan Schist Belt on the Geological map of Nigeria. Modified after Woakes et al.⁽⁴⁾

The Iseyin- Oyan schist belt continues into the Ibadan area and forms part of the late Archaean to Palaeoproterozoic banded gneiss–quartzite–schist sequence.^(5,6) Previous studies revealed undifferentiated schists as the most widespread lithology; quartzites occur near the margins of the schist belt while massive amphibolites represent mafic igneous rocks.⁽⁵⁾ More recent geological mapping⁽⁷⁻¹¹⁾ within the schist belt reported the occurrence of lithologic units similar to those reported in earlier studies. Based on mineral assemblages recorded in pelitic schist mapped within the Belt, higher grade metamorphism was suggested in the belt than in most northern schist belts⁽¹²⁾, whose structural style and magnetic properties are well elucidated.^(1,12)

The Precambrian Basement Complex rocks in the Itasa area, have previously received little attention. Much of the information on the geology of the area is contained in the geological map produced by the Nigerian Geological Survey Agency (NGSA)⁽¹³⁾ where it is revealed to be underlain by “Undifferentiated Schist” associated with many igneous intrusion of Older granite that metamorphosed surrounding rocks during

the Proterozoic era⁽¹³⁾. This study was therefore carried out to identify the type of schist within the area by undertaking detailed petrographic, geochemical studies and mineral chemistry on the rocks for proper assessment of their grade of metamorphism, geochemical characteristics and tectonic origin.

2 Study location and Geologic setting

The present area is located within the Iseyin-Oyan schist belt in Southwestern Nigeria. It is defined by the geographical coordinates of Latitude 8° 00' N and 8° 08' N and Longitude 3° 00' E and 3° 07' E.

The area is situated at the western fringe of South-West Nigeria. In this section, the main exposed lithologic units are the granite gneiss, quartz mica schist, amphibolite, porphyritic granite, biotite alkali granite, quartz diorite and pegmatite (Figure 2).

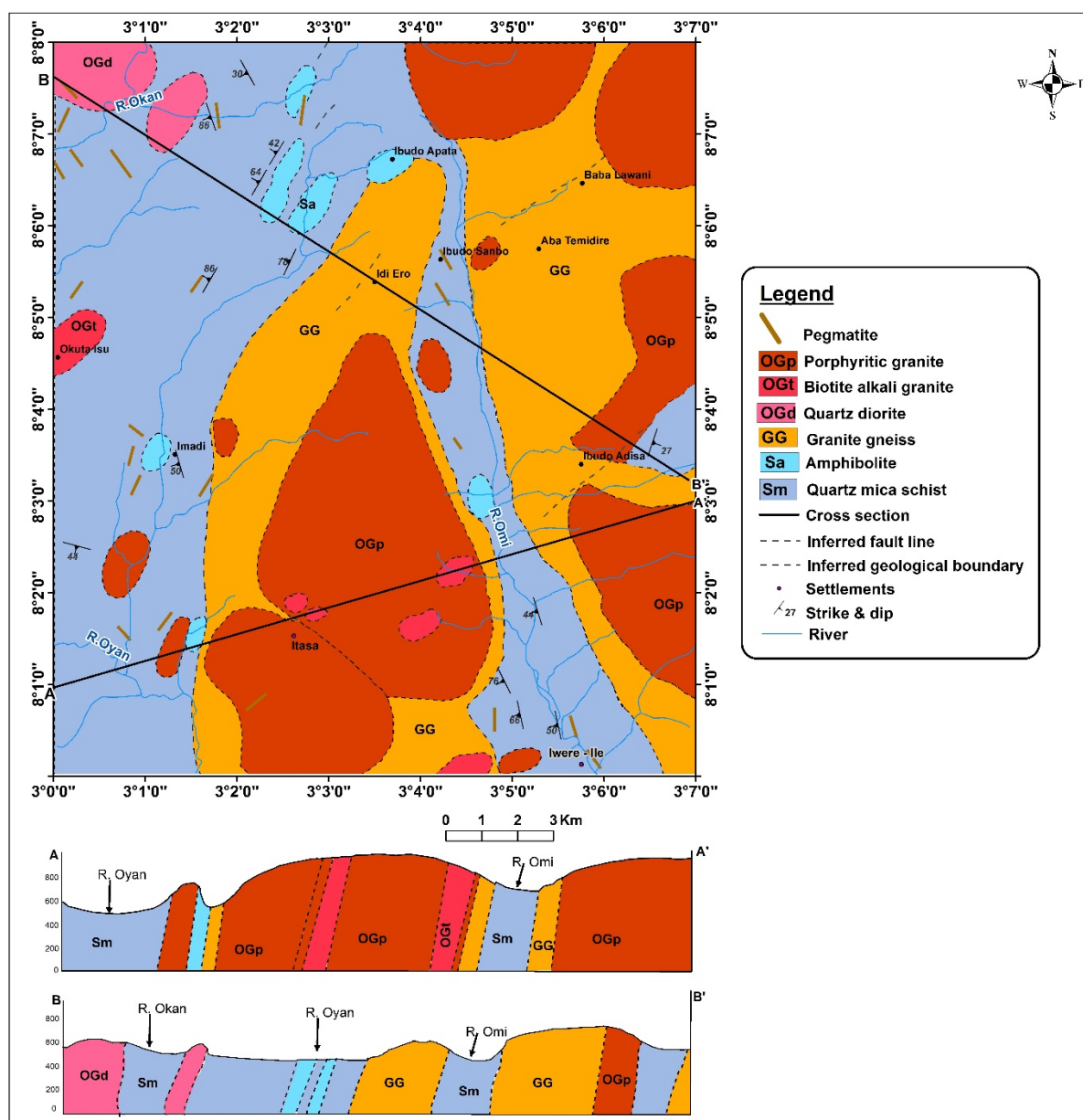


Fig 2. Geological map of the study area

The quartz mica schists, which are the focus of this study, generally trend in the NE-SW and dip to the southwest. Amphibolites occur in close association with the quartz mica schist as discontinuous lensoid bodies of small to large rocky boulders, trending NNE-SSW. Granite gneiss dominates the eastern and the central part of the area. Based on field relationship, it is regarded as an Older granitoid and occurs at the rim of other Older granitoid intrusives, notably, the coarse porphyritic granite. The granite gneiss is weakly foliated to porphyroblastic and with shearing around granitoid intrusions. Structural features on the sheared outcrops include pygmatic quartzo- feldspathic veins of about 2 to 10 cm thick. The veins are either concordant or crosscutting to the regional foliation trends. Quartz- diorite is mesocratic, medium to coarse-grained granitoid outcropping as bosses and low-lying discontinuous body intruding the quartz mica schist at the north-western part of the area. Porphyritic granite occurs as a high-level intrusion of Older granitoid outcropping as bosses, low-lying body and huge boulders. The porphyritic texture is defined by phenocrysts of feldspars and quartz surrounded by inequigranular groundmass of biotite, quartz and feldspars. Biotite alkali granite is medium grained mesocratic to melanocratic Older granitoid which mostly occur as minor enclaves within coarse porphyritic granite at the southern part of the study area with hand specimen showing mafic minerals and feldspars.

3 Material and Methods

A comprehensive fieldwork was undertaken where rocks within the study area were located, studied in-situ and sampled. Geological data related to the occurrence, field relationships and mineralogical-textural characteristics were obtained.

Petrographic studies were carried out in the petrography laboratory of the Department of Geology, The Polytechnic, Ibadan, Nigeria, using an Olympus binocular microscope. The mineral phase identification, mineral chemistry and geochemical analyses were performed at the University of Wolverhampton, United Kingdom.

Mineral phase identification was done using PANalytical Empyrean X-ray Diffractometer. X-ray diffraction pattern of these samples was recorded over a 2θ range of 50° to 70° . The diffractometer was equipped with a graphite monochromated Cu K α radiation source (8987 eV; $\lambda = 1.5418 \text{ \AA}$) operated at 40 kV and 40 mA for 30 s. A portion of each pulverised rock samples was put on the flat auto-plate and mounted on an auto-stand. A proportion of the X-rays were diffracted by the regular crystal structure of the samples. Mineral phase identification was made by searching the International Centre for Diffraction Data (ICDD) and Joint Committee on Powder Diffraction Standards (JCPDS) database files. Data processing was carried out using Xpert HighScore Plus software on a DEC Microvax Minicomputer interfaced to the diffractometer.

Fresh representative samples of quartz mica schists were selected after geological mapping exercise of Itasa area for detailed analysis. Mineral phases identifications were investigated using the XRD, mineralogical composition using Scanning Electron Microscopy equipped with an Energy-Dispersive X-ray (EDX) analyser and elemental composition analysed using X-Ray Fluorescent (XRF) and Inductively Coupled Plasma-Optical Emission Spectrometer (ICP-OES).

Mineral chemistry studies were carried out using a Zeiss EVO 50 (Zeiss, UK) Scanning Electron Microscope (SEM) attached to an EDX with an INCA 350 software (Oxford Instruments, Incax-sight, UK). Operating conditions of the instrument were 20 - 25 kV accelerating voltage, 15–20 nA beam current and counting times of 20–35 s per element. Analytical standards were high purity metals, well-characterized synthetic oxides and natural minerals. Analyses were made of plagioclase, biotite, garnet and other accessory minerals.

Geochemical analyses of the major oxides and some trace elements was determined using Epsilon XRF spectrometer by PANalytical at 4 kV using powder pellet discs. To prepare the pellet, 8.50g of the sample powder was weighed accurately, to which was added 1.50g of Licowax C Micropowder PM- Herzog organic binder. The homogenous mixture was placed in an aluminium cup and hydraulically pressed into pellets under high pressure of 20 tonnes. This was done to ensure the integrity of the sample under vacuum and the consistency of the surface to receive X-rays. Trace elements and rare earth elements (REE) within the samples were analysed using ICP-OES model SPS 3 Argilent Technology. Sample digestion was done using fusion following the method described by a team of researchers.⁽¹⁴⁾ Fusion with ammonium bifluoride (NH_4HF_2) salt in a perfluoroalkoxy alkaline (PFA) vial has been recommended for complete recovery of trace elements particularly the REE in rock samples.

4 Results and Discussions

4.1 Petrography

The schist is identified as quartz mica schist and covered about 40 percent of the area mapped. Petrologic evidence revealed that the quartz mica at the western part of the study area are closely associated with amphibolites, quartz diorite, biotite alkali granite and pegmatites. They are grey shaded, silk lusted, highly compacted and usually display clear schistose texture, with

small quartz bodies (Figure 3 A-D). The rocks are medium-grained and less contorted with thin foliation planes that are typically a few centimeter. The foliation planes are usually truncated by either ptygmatic folds, microfolds, 'boudinage' quartz or pegmatitic veins. Others are mainly restricted to the central part of the study (Figure 3E-G) and closely associated with granite gneiss, porphyritic granite, small to large pegmatite bodies but rarely with amphibolite. They vary from highly weathered to the relatively fresh outcrop. Where fresh, they show grey-silver-brown shades with silky lustre and a well-defined schistose structure, usually characterized by the presence of anatectic pegmatites swarm and small quartz bodies. Quartz veins which are either parallel or crosscutting the foliation are common. Their grain size ranged from fine to medium grained with a pelitic appearance.



Fig 3. Field photographs quartz-mica schist showing schistose texture (A) (coordinate $8^{\circ} 2' 30.7''$ N $3^{\circ} 0' 24.8''$ E Strike/Dip: $343^{\circ}/49^{\circ}$ SW); (B) showing ptygmatic fold of quartzofeldspathic vein (coordinate $8^{\circ} 0' 26.6''$ N $3^{\circ} 5' 16.1''$ E; Strike/Dip: $142^{\circ}/56^{\circ}$ SW); (C) showing shearing on a quartz vein; (D) showing minor fold on the outcrop; (E) along a river channel; (F) showing minor joint and (G) road cut exposure intruded by a pegmatite vein (coordinate: $8^{\circ} 0' 28.8''$ N, $3^{\circ} 5' 23.3''$ E; Strike/Dip: $314^{\circ}/50^{\circ}$ SW).

Mineralogically, the quartz mica schist at the western part are composed of biotite, muscovite, quartz, plagioclase, sillimanite, microcline and garnet while accessory minerals include titanite, zircon, apatite, magnetite and ilmenite (Figure 4 A-D). Biotite is usually dominant over muscovite; with the slim flakes longitudinally aligned. Muscovite generally intergrow with biotite. Sillimanites are observed as fibroid aggregate of acicular fibrolite in the quartz mica schist. The quartz mica schist at the central part are composed of biotite, muscovite, quartz, plagioclase, K-feldspars and opaque minerals while accessory minerals include titanite, magnetite, ilmenite and zircon (Figure 4E-H). Thin quartz aggregates occur between the schistose layers of the rock defining the thin banding noticeable in the rock. X- Ray diffractograms (Figure 5) is consistent with the petrographic data. Quartz, biotite, sillimanite plagioclase, orthoclase and microcline were identified on the diffractograms, of which, sillimanite (Figure 5C) is identified on the diffractogram from the western part of the study area. On the basis of the mineral paragenesis, the quartz mica schist reached amphibolite facies conditions.

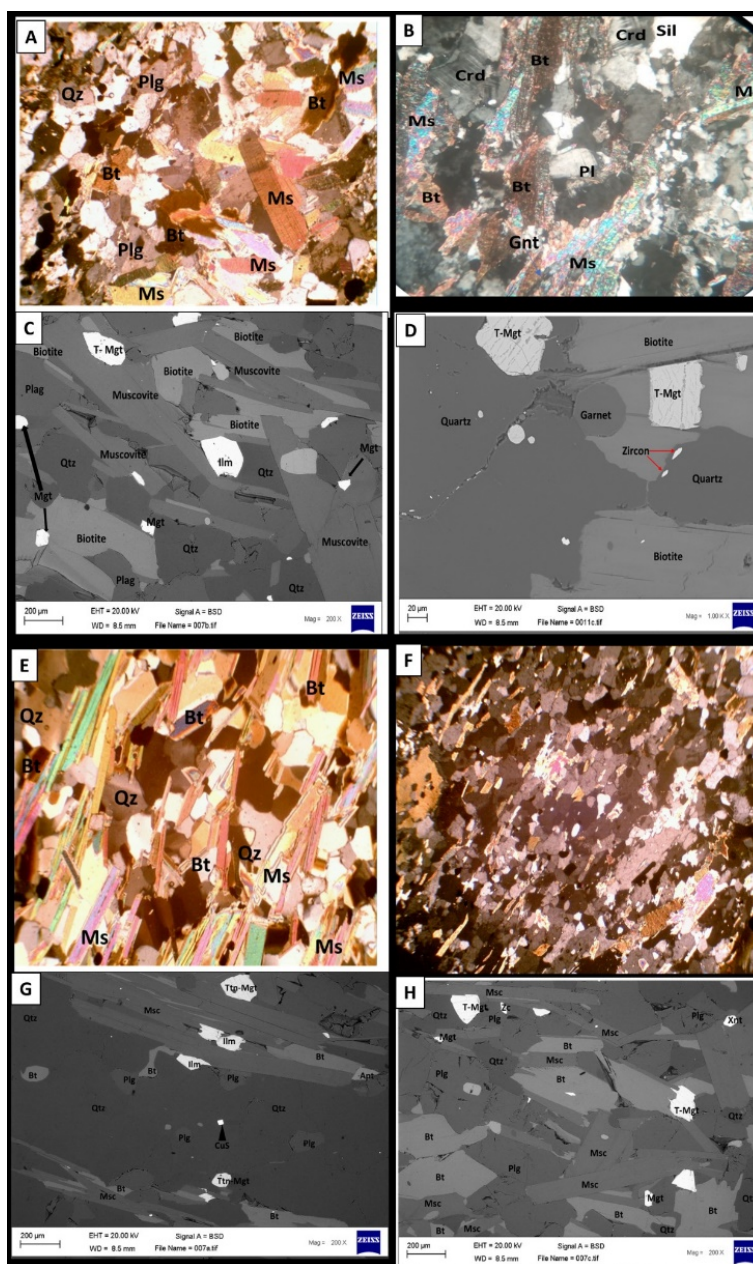


Fig 4. Photomicrographs and Backscattered electron images showing prominent foliation. Plag- Plagioclase, Qtz- Quartz, Msc- Muscovite, Bt- Biotite, Zrc- Zircon, T-Mgt- Titanomagnetite, Mgt- Magnetite, Ilm- Ilmenite. Sil- sillimanite, Crd- cordierite Gnt-garnet.

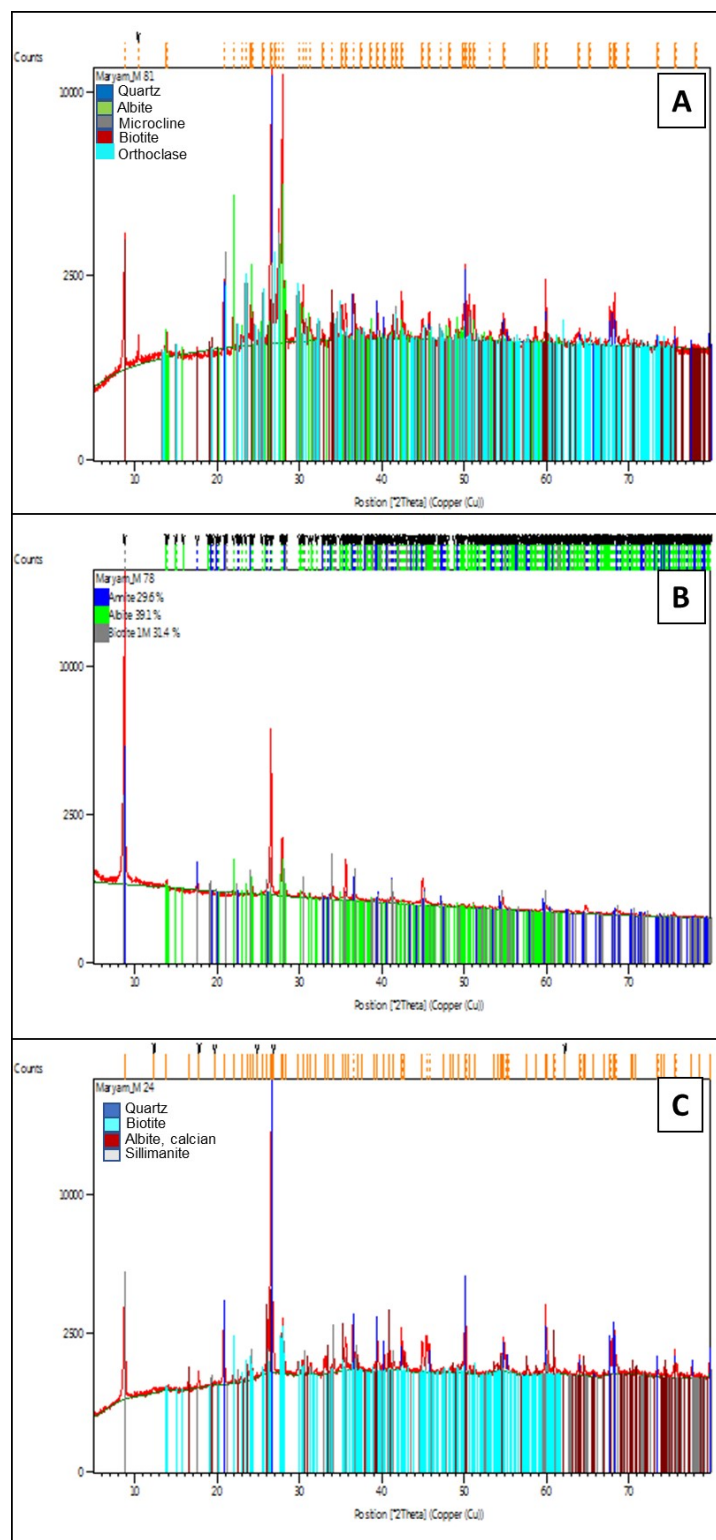


Fig 5. X- ray diffractograms of the quartz mica schist showing peaks of quartz, biotite, albite, orthoclase, microcline with (c) minor peaks of sillimanite.

Structural imprints show the different orientations of foliation in terms of dipping direction within the quartz mica schist (Figure 2) with implications for uplift/overturn folding. This may be linked with the occurrence of granitoid intrusives in close association with the schist. Lithostructural evidence suggests a clockwise overturn that may expose deeper roots of the quartz mica schist at the western part of the study. Growth of small grains of garnet and presence of sillimanite from quartz mica schist at the western part of the study implies higher metamorphic grade as these index minerals are absent in the central part of the area. These evidence suggest overturn of the schist as a contemporaneous event during the intrusion of granitic magma during Proterozoic era.

4.2 Geochemistry and geotectonic setting

A general petrographic description of the representative samples selected for geochemistry and mineral chemistry is given in the above-mentioned petrography. The geochemical characteristics of the quartz mica schists in the Itasa area are shown in Figure 6 while its chemical composition is shown in Supplementary Table 1.

Major oxide geochemistry showed SiO_2 concentration ranging from 56.4 – 71.6 wt.% with average concentration of 65.56 wt.%. The quartz mica schist from the central part of the study was more silica enriched with concentration exceeding 70 wt. %. This enrichment may be due to contamination from more acid intrusions closely bordering this area of the study underlain by quartz mica schist or were topmost layer of the metasediment that suffered from Paleo-weathering during or after the deposition of supra-crustals that were buried before metamorphism. Paleo-weathering may also account for the selective removal of Al and K during possible degrading of feldspars. Quartz mica schist from the western part revealed relatively lower silica concentrations (56.4 – 64.2 wt.%) and higher Alumina concentrations than those observed for samples from the central part of the area. Concentrations of other major oxides support differential degrees of metamorphism. Fe_2O_3 concentrations were slightly higher in samples obtained from the western part of the study as well as in MgO concentrations. CaO concentrations are varied and ranged from 1.5 – 3.1 wt.%. The alkali concentrations were discriminated and may be linked with different modal proportions of feldspar. Samples with lower SiO_2 concentrations revealed higher K_2O and lower Na_2O values.

The petrogenesis of the quartz mica schist as indicated on the $\text{Na}_2\text{O} - \text{Fe}_2\text{O}_3 + \text{MgO} - \text{K}_2\text{O}$ diagram⁽¹⁵⁾ (Figure 6A) shows that the protoliths of the quartz mica schist are greywacke at the central part and arkose at the western part of the study area. The chemical composition of the quartz mica schist clearly explains the nature of chemical weathering that produced the arkose and greywacke. The $\text{SiO}_2/\text{Al}_2\text{O}_3$ ratios in the quartz mica schist ranged from 2.67 to 5.24. The ratio is a common sedimentary maturation index that increases during weathering, transportation and recycling, due to an increase in modal framework quartz than the less resistant constituents, such as, feldspar and lithic fragments.⁽¹⁶⁾ It varies from around 3 in basic rocks to around 5 in acidic rocks, and greater than 5 or 6 in matured sediments.⁽¹⁶⁾ This implies that weathering and transportation increase from the central part of the study area to the western part of the study which is probably the alluvial fan sediments. Following the work of Nesbitt and Young,⁽¹⁷⁾ as applied to clastic rocks⁽¹⁸⁾, the values of Chemical Index of Alteration (CIA) ranged from 58 to 71. CIA is the most frequently used geochemical index to quantitatively estimate source-area weathering intensity and understand paleoclimate conditions.⁽¹⁶⁾ It is defined as the molar ratio $[\text{Al}_2\text{O}_3 / (\text{Al}_2\text{O}_3 + \text{CaO}^* + \text{Na}_2\text{O} + \text{K}_2\text{O})] \times 100$ (CaO^* is the Ca in silicates). The CIA values in this study also increase towards the western part of the study area from relatively unweathered to moderate alteration of the protoliths before removal, transportation and subsequent deposition.⁽¹⁹⁾

The relatively immobile High Field Strength Elements (HFSE), Zr, Nb, Y in the schist show contents similar to those of the upper crust⁽²⁰⁾ (Figure 6B). HFSE are incompatible during most magma crystallization and anatectic processes⁽²¹⁾, and are usually less water-soluble, thus, are resistant to change during weathering and alteration processes, hence, reflecting provenance compositions.⁽²⁰⁾ The Large Ion Lithophile Elements (LILE) Rb, Sr and Ba show slight variation with respect to the upper crust and within the samples. Generally, there is a slight impoverishment in Sr with respect to the UCC⁽²⁰⁾. Ba contents in the central part are higher than in the upper crust which may be related movement of metamorphic remobilized fluid during the Pan African or earlier event.⁽¹⁹⁾

The primitive mantle⁽²²⁾-normalized rare earth elements (REE) diagram (Figure 6C) displays a relatively similar pattern in the schists, indicating progressive depletion in the Light REE and a weak depletion to almost flat characteristic in heavy REEs. The fractionated LREE/HREE pattern, ($\text{LaN}/\text{YbN} = 15$ to 23), the fractionated Light REE ($\text{LaN}/\text{SmN} = 4$ to 8), nearly flat Heavy REE patterns, ($\text{GdN}/\text{YbN} = 1-2$) and characteristic negative Eu anomaly. These features suggested derivation from the upper continental crustal materials.⁽²⁰⁾

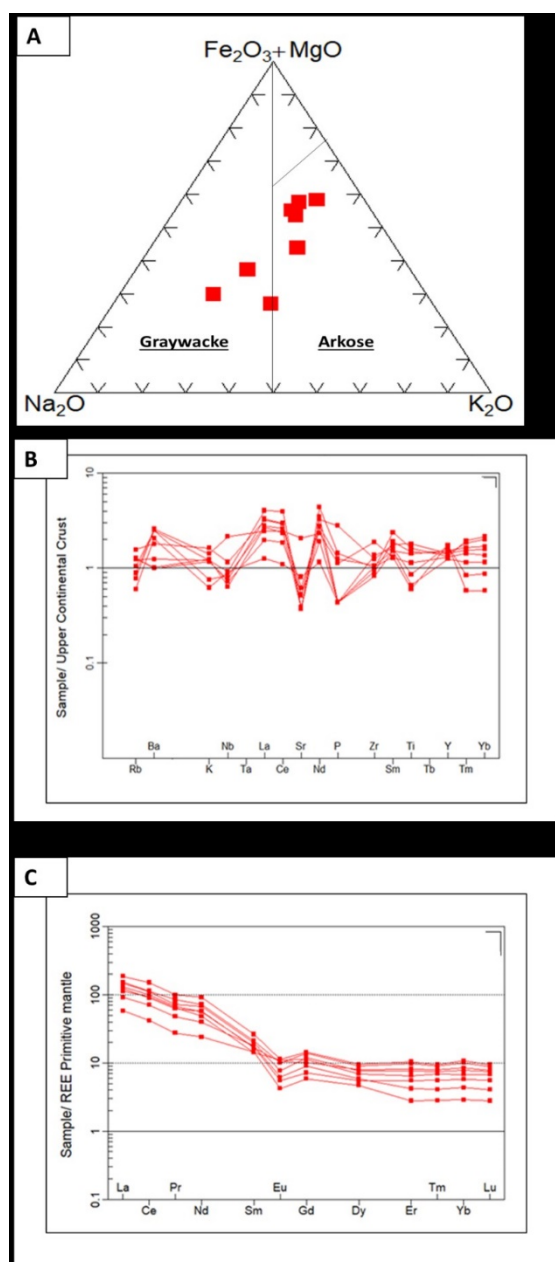


Fig 6. (A) Geochemical characteristics of the quartz mica schist on the $\text{Na}_2\text{O} - \text{Fe}_2\text{O}_3 + \text{MgO} - \text{K}_2\text{O}$ diagram⁽¹⁵⁾ (B) UCC⁽²⁰⁾ normalized spidergram; and (C) Primitive mantle⁽²²⁾ normalized REE patterns

It has been reported that sediments geochemical abundances can be related to the processes of plate tectonics, thus, making geochemistry a reliable tool in the recognition of ancient tectonic environments.^(23,24) Many major oxide discrimination diagrams have been used to discriminate different tectonic settings.^(24,25) Systematics of $\text{SiO}_2 - \text{K}_2\text{O}/\text{Na}_2\text{O}$ have been linked to geotectonic environment⁽²⁴⁾ because both variables increase from volcanic arc to active continental margin to passive margin setting. In this study, however, the $\text{SiO}_2 - \text{K}_2\text{O}/\text{Na}_2\text{O}$ trend matches with those sediments deposited at the active continental margin (ACM) (Figure 7 A). A similar trend was also observed on the $\text{SiO}_2/\text{Al}_2\text{O}_3$ versus $\text{K}_2\text{O}/\text{Na}_2\text{O}$ diagram⁽²⁵⁾ (Figure 7B). The ACM includes thick continental margins of the Andean type sedimentary basins and the strike-slip types. These basins are found on or neighbouring to a thick continental crust made up of rocks of older fold belts and the sediments are derived from granite-gneisses and siliceous volcanics of the uplifted basement. On the basis of evidences from the eastern and north-eastern

margins of the West African Craton, it has been noted by previous authors that the Pan-African trans-Saharan belt emerged by plate tectonic processes involving collision of the active margin of the Taureg shield and the passive continental margin of the West-African Craton, about 600 ± 10 Ma.^(6,26,27) There was crustal melting towards the end of the collision between the Tuareg shield and the subducted oceanic crust which is concluded to have reactivated the internal region of the Pan African belt forming the Pan African granitoids.

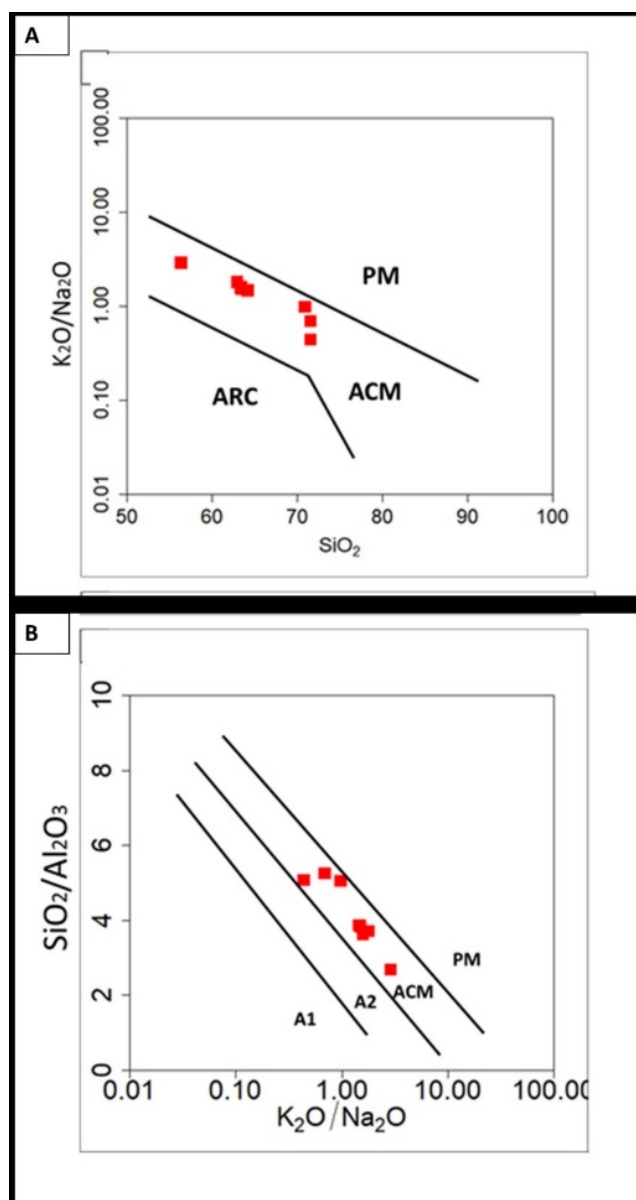


Fig 7. Tectonic discrimination diagrams for the quartz mica schist (A) SiO_2 - $\text{K}_2\text{O}/\text{Na}_2\text{O}$ ⁽²³⁾ and (B) $\text{SiO}_2/\text{Al}_2\text{O}_3$ versus $\text{K}_2\text{O}/\text{Na}_2\text{O}$ ⁽²⁵⁾ indicating deposition of sediments in the active continental margin (ACM). PM- passive margin; ARC -oceanic island arc margin; A1- arc setting, basaltic and andesitic detritus; A2 -evolved arc setting, felsic plutonic detritus.

4.3 Mineral chemistry

Biotite: The mineral chemistry of biotite in the quartz mica schists are presented in Supplementary Table 2. The table includes structural formulae of the biotite calculated on the basis of 22 Oxygen. The analyses indicated that two types of biotites were formed in the schists. According to classification diagrams (Figure 8 A-B)^(28,29), the biotites in samples of quartz mica schist at the central

part of the study are rich in Fe, thus annitic- siderophilic end members, and characteristics of granitic rocks while those from the western part are rich in Mg, thus phlogopitic-eastonite end member and characteristics of mafic rocks.

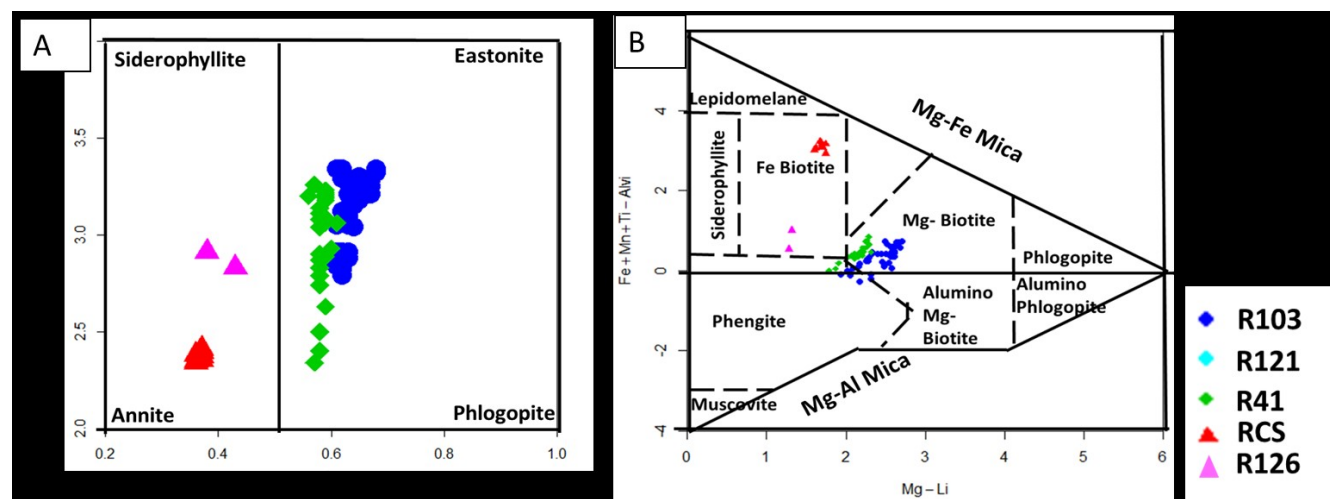


Fig 8. Plots of (A) Al^{IV} against $Mg/(Mg + Fe)^{(28)}$; and (B) $(Mg-Li)$ vs. $(Fe+Mn + Ti- Al^{VI})^{(29)}$ showing the biotite types.

Plagioclase: The mineral chemistry of plagioclase in the quartz mica is presented in Supplementary Table 3. This table includes their structural formulae calculated based on 32 Oxygens. It was revealed that the albitic content (very high Na_2O but low CaO contents) of plagioclase decreases towards the western part of the study area. They are oligoclase with subordinate andesine in the west, whereas, albite in the central part of the study area (Figure 9).

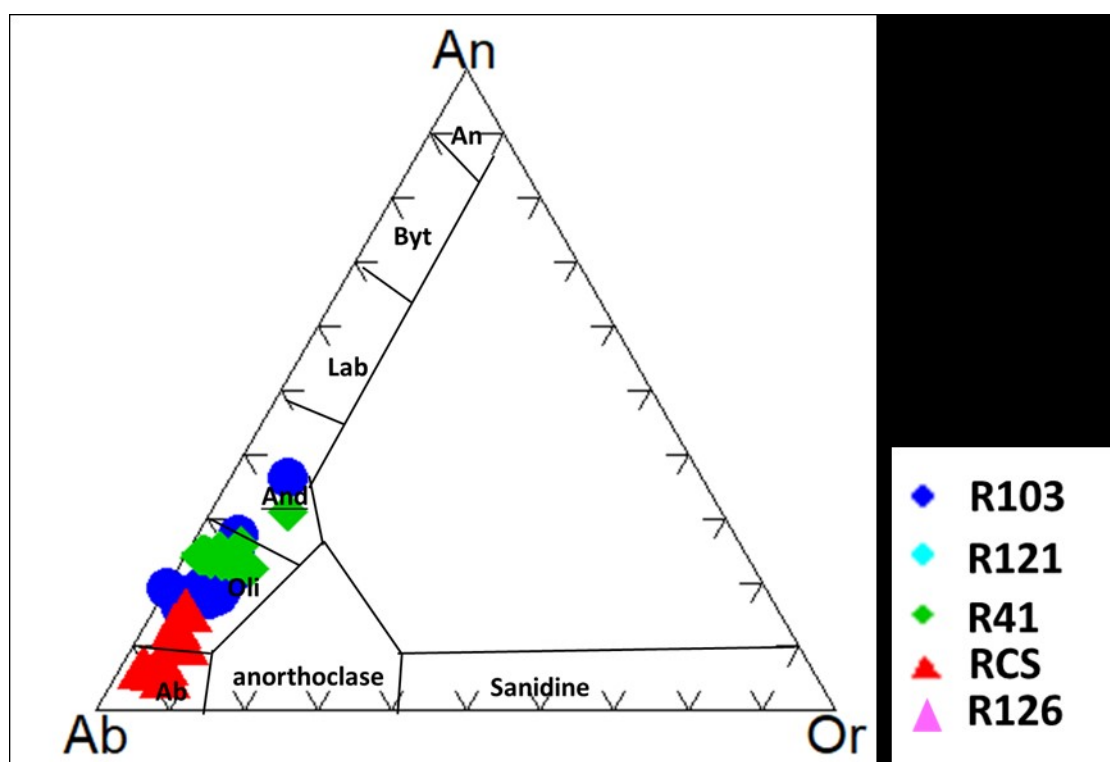


Fig 9. Classification of the plagioclase in the quartz mica schist into albite to andesine compositions as shown on the Ab-An-Or diagram.⁽³⁰⁾

Garnets: The mineral chemistry of garnets in the quartz mica are presented in Supplementary Table 4. The pyrope component is predominant in this garnet with content between 56 to 58%. The almandine component is less predominant with content between 32 and 34 %. The garnet is essentially pyrope-almandine solid solutions (Figure 10) with the garnet being more of pyrope than almandine⁽³¹⁾ indicating the formation of the schist under high-pressure metamorphic conditions. There is no difference between the analysis from the core and rims of these garnets possibly indicating temperature equilibrium during its growth.

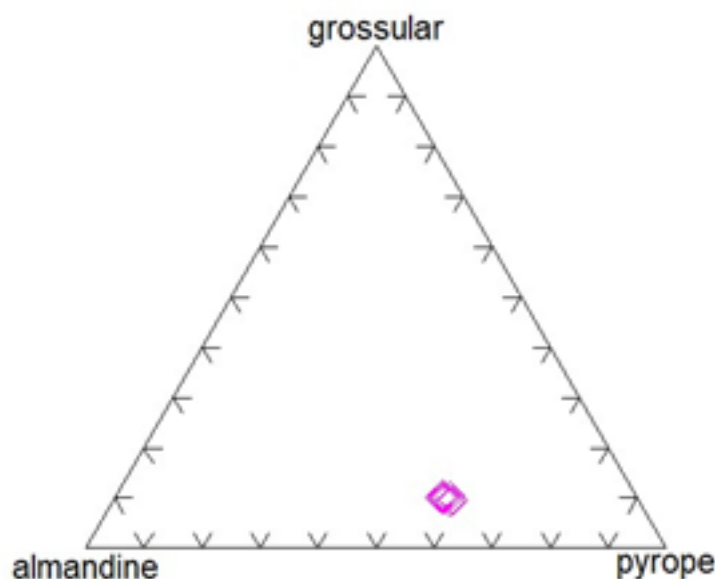


Fig 10. Composition of the garnet in the quartz mica schists of Iseyin-Oyan schist belt after Coleman et al.⁽³¹⁾

5 Conclusion

The undifferentiated schist has been identified as quartz mica schist having lateral variation in grade of metamorphism from medium to high grade. Field evidence revealed that the schists are silky lusted with well-defined schistosity. Mineral assemblages indicate lower to upper amphibolite facies grade of metamorphism. Structural imprints with implications on uplift and possible folding within the schist may be linked with their close association with granitoid intrusives. These evidences suggest a clockwise overturn which explains an upper amphibolite facies schist exposed at the western part of the study with mineral-ins of garnet and sillimanite believed to be deeper layers of the regionally deposited supracrustals metamorphosed during probable Eburnean times.

Geochemical characteristics of major oxides supported discriminations based on metamorphic facies. This evidence implies differential degrees of metamorphism during deep burial metamorphism from the central and western part of the study. HFSE and LILE are similar to the average upper crustal, though, Ba and Ti showed slight differences that may be linked with mobility of ions during metamorphism. Crustal contamination during metamorphism and uplift associated with granitoid emplacements may be adduced for the enrichment in LREE pattern. Depletion of heavy rare earth element with pronounced Eu anomaly pointed to influence of upper continental crust and that feldspars played major role during these geologic processes. The mineral chemistry revealed presence of pyrope-almandine garnet in the quartz mica schist, which implies high pressure-temperature metamorphism in the western part of the study but completely absent within the schist that underlain the central part.

The precursors of the quartz mica schists are possibly arkosic and greywacke sands deposited within active continental margins that form narrow belts of schistose rocks with the Precambrian Basement complex of Nigeria. The events associated with this active margin may be responsible for the uplift and overturning of deeper layers of metamorphosed supracrustals.

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